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VOLUMETRIC EQUATIONS MODELING FOR TWO EUCALYPTUS CLONES ESTABLISHED IN A SILVOPASTORAL SYSTEM

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ABSCTRACT
The timber stocks estimation is one of the most important information for understanding the potential of a forest stand. In this sense, the most used tool is modeling volumetric equations. Several studies have been developed in order to define volumetric equations for different forest stands, species, sites, management systems, planting spacings, etc. However, these models do not always fit to all species and conditions. Specifically in silvopastoral systems, in which is recommended the use of wider spacings between tree rows, the dendrometric behavior is differentiated from that observed in pure stands. Modeling volumetric equations studies for trees established in this kind of system are still scarce. So, this work aimed to model volumetric equations for two eucalyptus clones established in silvopastoral in mountainous areas in the Zona da Mata de Minas Gerais, in order to estimate the timber volume of the first thinning at 42 months of age. Both materials were established in planting densities of 555 trees per hectare. The first step was to characterize the diameter distribution and scale the trees by using the tree-model method for volume yield estimation in each plot. After that, six volumetric models, selected in the forestry literature, were tested. All tested models showed a high level description of the total timber volume at 42 months of age. However, for both clones, the model that presented the best adjustment was the Spurr Logarithimic.
Palabras claves: *Eucalyptus*, mathematical models, forest mensuration, silvopastoral systems

INTRODUCTION

The timber stocks estimation is one of the most important information in forest management, as it allows the forest manager to know the available potential yield of a forest stand, given that the individual tree volume provides data for the evaluation of wooden stocks and analysis of the productive potential of forests (Thomas et al., 2006).
In this sense, the most commonly used tool is modeling volumetric equations whose parameters are determined by regression. This method has been considered an effective procedure on quantification of wooden stocks in forest stands (Leite and Guimarães, 1996).
Several studies have been developed aiming to define volumetric equations for forest stands estimation, considering different species, sites, management systems, planting

spacings, etc. However, in spite of the efficiency of some allometric models, they do not always fit all species and conditions (Thomas et al., 2006).
Besides the use of wider spacings, silvopastoral systems are managed under thinning regimes, in order to provide wooden multiproducts. After each thinning the spacing between trees is increased leading to a different dendrometric behavior from that observed on pure stands. As noted by Couto et al. (2002), trees established in wider spacings tend to show larger taper forms, mostly because, in these situations, the diameter growing rate is higher than the height growing rate. In this sense, studies about modeling allometric equations for estimating wood stocks are rare.
This work was carried in order to model allometric equations for wood stocks estimation of two eucalyptus clones established in a silvopastoral system, at 42 months of age, due to the first thinning.

MATERIAL AND METHODS
This work was carried in a 50 hectare area located at a private property in Coronel Pacheco, Zona da Mata de Minas Gerais, Brazil. Two clones of a hybrid of *Eucalyptus grandis x Eucalyptus urophylla* (named as clone 1 and clone 2) were used. The trees were established in rows composed by two lines of trees spaced by 3 meters between lines and 2 meters between plants. Each row was spaced by 15 meters, totaling 555 trees per hectare.
The first step was to characterize the diameter distribution by measuring the total height (H) and the diameter at breast height (DBH) of 120 trees distributed in 4 experimental units of 476 m^2. The trees were distributed in diameter classes of 5 cm. After that, by using using the tree-model method, three trees were selected, by diameter class, to be scaled. To scale the trees the Smalian's model was used, considering a 1.5 m section length. The trees used were from a systematic thinning of 50% of the original stand.
From the data of the scaled trees, six volumetric models, selected among the forestry literature, were tested due to DBH and H, like described on Table 1.

Table 1 – Volumetric models tested for timber stocks estimation of two eucalyptus clones established in silvopastoral systems at 42 months of age

Equation	Model	Author
1	$lnV=\beta_0+\beta_1*lnDAP+\beta_2*lnHt$	Schumacher-Hall (logaritimizado)
2	$lnV=\beta_0+\beta_1*ln(DAP^2*Ht)$	Spurr (logaritimizado)
3	$lnV=\beta_0+\beta_1*lnDAP+\beta_2*DAP$	Brenac
4	$V=\beta_0+\beta_1*DAP^2$	Koperzky e Gehrhardt
5	$V=\beta_0+\beta_1*DAP+\beta_2*DAP^2$	Hohenald e Kreen
6	$V=\beta_0+\beta_1*DAP$	Berkhout

The volumetric model selection was made due to the R^2, standard error (S_{yx}), F value and a weighted value of statistical parameters, like the one made by Thomas et al. (2006).
The weighted value of statistical parameters calculation followed the methodology described by Thiersch (1997). Thus, weight values were assigned for each statistical parameter, ranking them due to its efficiency. The most efficient equation was assigned with 1, the second was assigned with 2 and thus successively. After that, the weighted values of each statistic parameter were summed resulting in a final value for each model, and the equation that showed the lowest score was recommended as the most appropriate for the timber stocks estimation.

RESULTS AND DISCUSSION

The statistical parameters of volumetric equations modeling for each eucalyptus clones, at 42 months of age, are shown on tables 2 and 3.

Table 2 – Statistical parameters of volumetric equations modeling for timber stocks estimation of clone 1, at 42 months of age, established in a silvopastoral system

Equation	Coefficients			R^2	S_{xy}	CV	F
	β_0	β_1	β_2				
1	-9,7641	2,0100	0,8111	95,84	0,0707	57,66	310,97
2	-9,7772	0,9411		95,79	0,0699	56,98	636,38
3	-8,7041	2,2596	0,0335	93,81	0,0863	70,31	204,67
4	-0,0418	0,0007		92,58	0,0106	8,64	349,56
5	0,0690	-0,0155	0,0013	92,72	0,0107	8,72	171,90
6	-0,1958	0,0216		91,94	0,0110	9,00	319,58

Table 3 – Statistical parameters of volumetric equations modeling for timber stocks estimation of clone 2, at 42 months of age, established in a silvopastoral system

Equation	Coefficients			R^2	S_{xy}	CV	F
	β_0	β_1	β_2				
1	-9,07283	2,124812	0,457655	97,52	0,06	37,06	334,25
2	-9,58412	0,916445		97,10	0,06	38,95	602,37
3	-7,11992	1,600099	0,050692	97,18	0,06	39,52	292,79
4	-0,03284	0,000741		95,66	0,01	7,52	396,50
5	0,06016	-0,01176	0,001105	95,79	0,01	7,61	193,43
6	-0,21843	0,023685		94,57	0,01	8,40	313,73

The data presented on tables 2 and 3, reveal that all models showed a height degree of description adjustment of timber stock.

Tables 4 and 5 present the ranking, based on weighted value of statistical parameters method for each clone.

Table 4 - Weighted value of statistical parameters for timber stock estimation of clone 1, at 42 months of age, established in a silvopastoral system

Equação	Escores dos Parâmetros Estatísticos				VP
	R^2	S_{xy}	CV	F	
1	1	2	2	4	9
2	2	3	3	1	9
3	3	1	1	5	10
4	5	6	6	2	19
5	4	5	5	6	20
6	6	4	4	3	17

Table 5 - Weighted value of statistical parameters for timber stock estimation of clone 2, at 42 months of age, established in a silvopastoral system

Equação	Escores dos Parâmetros Estatísticos				VP
	R^2	S_{xy}	CV	F	
1	1	3	3	3	10
2	3	1	2	1	7
3	2	2	1	5	10
4	5	6	6	2	19
5	4	5	5	6	20
6	6	4	4	4	18

Considering these results, based on the Weighted Value, the model that presented the best fitting to timber stock estimation was the Spurr Logaritmic. Müller et al. (2009) observed that, for *Eucalyptus grandis*, at 10 years of age, established in a silvopastoral system, the Schumacher & Hall allometric model was the one that presented the best adjustment.
In this sense, Campos& Leite (2002) observed that the Schumacher & Hall allometric model, has been the most spreaded model due to its statistical properties, since it results, almost always, into unbiased estimates. However, the results from this work show that there is a need for more studies about modeling equations for timber stock estimation, in silvopastoral systems.

CONCLUSIONS

- All tested models showed a height degree of description adjustment of timber stock;
- The volumetric model that best fit the dependent variable volume description, at 42 months of age, based on the Weighted Value model, was the Spurr Logaritmic.

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